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DESIGN AND CONSTRUCTION OF SOLAR POWERED FABRIC DRYER

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ABSTRACT

In recent times, global climate has been marked with unpredictable patterns characterized by flash floods, rising temperatures, desertification, melting glaciers as a result of global warming. The aftermath of incessant and indiscriminate fossil fuel combustion is a major contributor to the global warming quotient. In the wake of this unnerving fact, current research focus is on discovery and utilizing of alternate energy sources devoid of these debilitating effects. This search has ultimately led to solar energy which is a fore most sustainable energy resource and readily available in many parts of the globe. A second objective is that different seasons affect the peak sun hour (PSH) available in various localities. The unpredictability of isolation is the problem this research seeks to address. This solar dryer was constructed with one 200 W, monocrystalline silicon solar panel connected in circuit to a DC motor and an exhaust fan. The drying cabinet which houses the dryer is also made of solar absorbent materials thus, evaporation occurs through the walls and the roof. The working principle of the solar drying system is based on the utilization of solar energy to dry any type of fabric loaded into it. The designed solar powered cloth dryer has an efficiency of 66.43% achieved in 1 hour and 30 minutes. This drier was fabricated solely from environmentally friendly materials.

***KEYWORDS:** Solar Dryer, Panel, Fabric & Drying Cabinet*

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Original Article

1. INTRODUCTION

The process of drying is one of the oldest and most wide spreading in all chemical engineering operations. Pre-historic drying is a process that is as old as man himself, it involves the removal of water content from the surface of a material through evaporation. There are different types of drying methods: Convection or direct drying, indirect drying, dielectric drying or microwave drying, freeze drying or lyophilization, supercritical drying or superheated steam drying and natural air drying. Drying is a very important operation in all industrial processes and daily needs that require a significant typical energy. It has been reported that drying consumes 12–20% of total energy supply in the industrial sector. This reinforces the fact that, drying is one of the most dominant units involved in operations. A lot of losses in crop production history are attributable to moist conditions. In produce drying, a complicated process of heat transfer that is dependent on external parameters such as, air, temperature, humidity and speed is involved. Advances in this sphere saw the application of desiccant properties, surface characteristics- either smooth or raw, chemical compositions like sugar, starch and so on. This encompasses the use of a substrate's physical structure to control the dying process (Suntivarakorn *et al.*, 2009).

Solar energy applications are classified into direct applications such as domestic water heaters, drying and indirect applications those that include a solar energy concentration system and/or the use of a photovoltaic system. Solar thermal applications are found in various forms of technological devices used for energy, heating, drying, cooking and also in refrigeration. In its natural form, wet clothes generally use natural forms of solar and wind

energy to dry. The time factor was not a constant but varied with seasons and geographical latitude on the globe. In order to promote scientific drying, there was an urgency to define the parameter of time, *t*. This brought in its wake the adoption of several technologies that use electricity and chemical sources becoming the most popular especially in urban areas. Urgency arose with the progression of housing types to condominiums and high-rise houses, where there is limited airflow and sunlight on cloudy days. In addition, laws were promulgated and natural drying in some housing areas was prohibited for esthetic reasons. An immediate solution was provided by domestic electrical dryers but, it was not long lasting because they are prone to high expenses and inefficiency (Mahlia *et al.*, 2010).

There have been a number of research incentives on dryers. Researchers having studied the trend in development of drying methods first began including heat pumps with multi-functional heat and time-varying input. This progressed to low pressure and low superheated current drying, there was a limitation due to the low pressure requirement. This was modified to normal atmospheric drying, more in-depth research brought about the osmotic pre-treatment and then microwave vacuum drying (Bolaji and Olalusi, 2008). A change in research perspective produced a simple mixed-mode dryer from locally available materials (Bolaji, 2005). A need for empirical solution resulted in evaluating the performance of a solar dryer for the preservation of food crops. The analysis entailed plotting temperature rises with time as a variable factor for determining the output performance. The outcome revealed 74% increment in 180 seconds. The drying speed and the efficiency of the system were given as 0.62 kg/h and 57.5% respectively (Sarsavadia *et al.*, 2007).

A peculiar challenge associated with outdoor drying is the contamination of fabric by dust and other particles. Use of washing machine dryers does not eradicate the moisture completely, the drying only takes less time and the clothing still gets in contact with atmospheric contaminants. Drying time is even less when drying clothes with a solar dryer, this reduces the incidence of contamination by another factor. The solar dryer works on the principle of forced convection of auxiliary heating, which remains operational in extreme weather conditions such as winter. In tropical countries that are devoid of winters, energy efficiency is a topical issue regularly being addressed by global government. Thus, a solar dryer would be a welcome development for cutting down the burgeoning electricity charges. This research objective is one of the such efforts which seeks to construct a fabric dryer and determine its efficiency in order to reduce energy consumption.

2. TYPES OF SOLAR DRYER

The concept of the solar drying is not new. But the solar dryers designed so far have never been substantially marketed. These work with regard to the principle of natural air convection, resulting in slow drying. However, the drying process is accelerated by forced circulation. Solar drying is an especially suitable method in the hottest parts of the world as there is plenty of sunlight. The year-round air temperature is high and relatively constant. Solar dryers' designs are constructed to make efficient use of the sun's heat. They can improve the sun drying rate in the right climatic conditions. These include higher drying temperatures, leading to shorter drying times and the ability to dry at a lower final content of moisture, pest protection and contamination of dust. In local laboratories, they are cheap and easy to build. Solar dryers are made of transparent panels on a black chamber or a collector to absorb heat rays from the sun. Usually, polyethylene is used to paint the panel, but after a few months it becomes yellow and opaque and has to be replaced. More plastic films are now available that are not easily damaged by sunlight and should be used as much as possible. Although they cost more, they have a half-life of about 5years or longer. Tilting the collector to the right angle to the sun is very important. The angle must exceed 15° to allow rain water to exit the panel and must lean towards the midday sun at 90°. In the northern hemisphere, the panel should be oriented to the south, while in the southern hemisphere the panel is positioned away from trees or buildings to avoid

shadowing effect. Solar drying, which is direct or indirect drying, can be shown in two ways. Due to the quality of the products after drying, indirect drying is more effective than direct drying. Direct drying is a traditional and basic drying method. It involves the product's direct exposure to solar radiation, which allows humidity to be released into the atmosphere. The movement of air is due to the difference in density. There are two ways to get this method; direct and indirect means.

2.1 Direct Solar Drying

Direct solar drying has a transparent cover to protect the products against weather and other natural events. It is a passive method involving the drying of thin layers; where products in large areas are exposed to solar radiation (Xie *et al.* 2011). This process lasts until the products are dried to the required level of moisture for a long time. It involves drying product in open air. For grains, direct outdoor solar drying is mostly useful. The only advantage is that compared to the indirect type, it is less expensive. Products usually spread between 10 and 30 days on floors. It is the simplest method, but it has some disadvantages:

- It is dependent on the climatic conditions and requires very large surface areas and long exposure to the sun.
- The drying of the garments can never be easily controlled.
- Clothes are most often exposed to all types of weather and changes.
- Direct exposure of sunrays to clothes reduces the quality of the clothes.

2.2 Indirect Solar Drying

Indirect solar drying was shown to be more efficient and effective than direct solar drying. The air is heated by a solar flat-platform collector or by a type of solar collector. The heating process can be active or passive. The heated air goes to the cabin where the products are stored; convection or diffusion can cause loss of moisture in the products. The main disadvantage of the indirect type is the initial high costs in getting the dryer. This method prevents direct radiation from the solar. The disadvantage of direct solar drying, however, is reduced.

The advantages of the indirect solar dryer are:

- Drying rate is high, relative to direct solar drying.
- The drying of the garment can be controlled easily.
- Direct exposure to solar radiation is avoided.

3. DRYING MECHANISM

During the drying process, heat is needed to remove moisture from a material, and the air flow helps to eliminate evaporated moisture. A drying process involves two fundamental mechanisms: one is the movement of humidity from the inside of the material to the surface, while the other is an evaporation of humidity from the surface to the air. A textile drying requires a complex heat and mass transfer process, which is subject to external variables, i.e. temperature, humidity, airflow rate and internal variables. It depends on surface properties, chemical composition, physical structure, product size and shape. Depending on whether the material is hygroscopic or non-hygroscopic, the speed of movement of moisture from the inside of a fabric to the outside air varies from one fabric to another. It can be dried to a level of zero humidity for non-hygroscopic materials, while for hygroscopic materials like most food products there will always be residual moisture content.

In hygroscopic material moisture remains in the material due to closed capillaries or surface forces and the in adherent moisture in the matter due to the water's surface tension as illustrated in Figure 1(Mumba, 1995). When exposed to air due to the relative humidity of the air, hygroscopic material will absorb moisture or desorb moisture. The moisture level of the equilibrium is therefore important during the drying process as this is the minimum moisture required for drying at a given drying conditions. However, further information can be obtained if the drying speed dM/dt with respect to the moisture content M is represented in Figure 2. For non-hygroscopic material, a constant rate of drying ends followed by critical humidity content by a decrease in the drying rate. The non-hygroscopic material drying rate constant is the same, while the falling speed period is quite different. During drying the rate reduced for non-hygroscopic materials, the drying rate continues to decrease until the moisture content becomes zero. Drying occurs by drying thin layers or drying deep layers. Thin layer products are mostly fruit and vegetables. The product is distributed over all thin layers of the air surface which is exposed to the product and Newton's cooling law applied to the fall region.

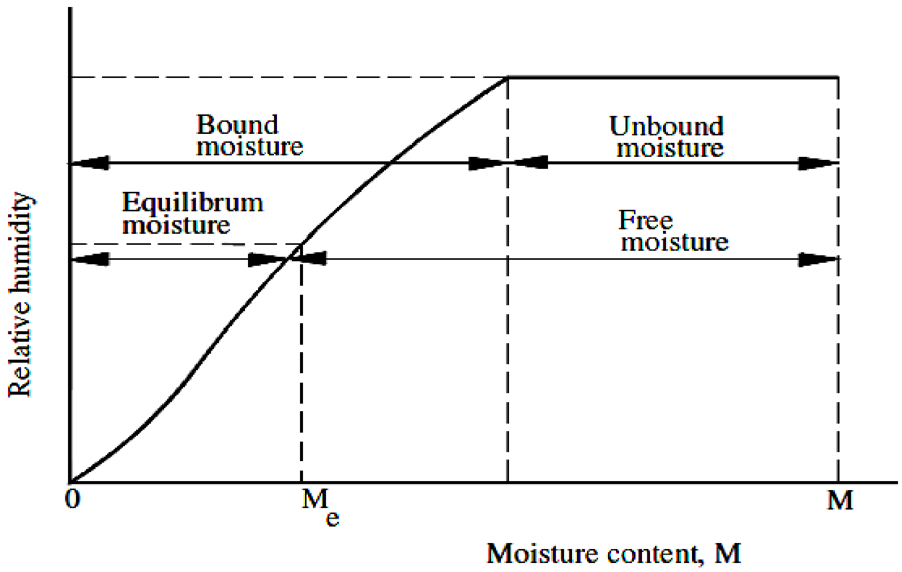

Figure 1: Moisture in the Drying Material (Mumbai, 1995)

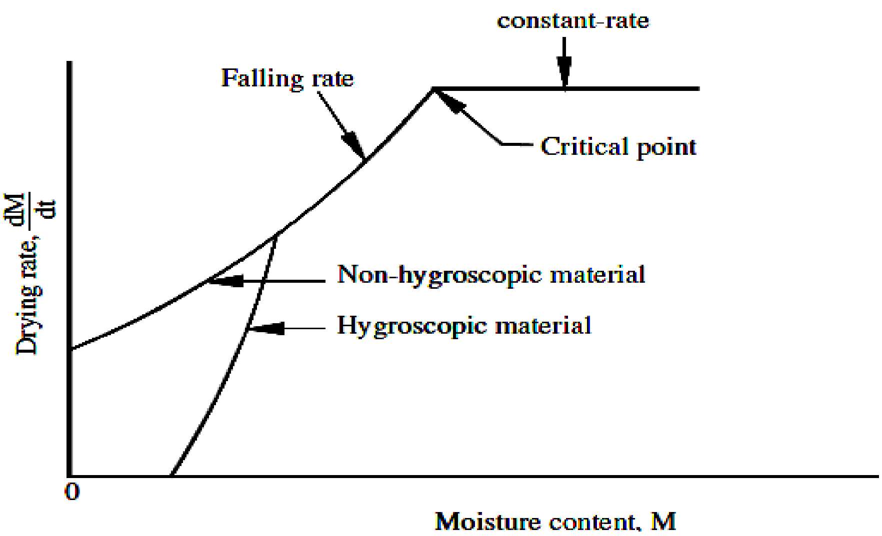

Figure 2: Typical Drying Rate Curve.

4. MATERIALS AND METHODS

The building materials for the cloth air dryer are economical and easy to get at the local market. The aluminum composite panel (poly carbon board) is the main material used. Aluminum was chosen because it is economical, lightweight, rigidity, easy to apply, unbreakable, resistant to strain, weather resistant and availability in many colours. The portable solar dryer was designed using the following materials; hinges and handles for the dryer's door, nails, screws, silicon glue, nuts and bolts as fasteners, adhesives, a solar panel for capturing sunrays to create photovoltaic power, a switch to power on the device, capacitors to stabilize the voltage of the device, diodes to help flow the current in one direction and to prevent backward current to the panel, aluminum composite panel board to reflect heat and provide support, DC motor to serve as a vacuum and a fan and wood – the casting of the system.

Two main components of the solar cloth dryer are; the drying cabinet and the solar collector unit (Sordia *et al.*, 1985). The drying cabinet unit consists of a rectangular unit in width and depth of about 180 cm and 52.5 cm. This cabinet has an air tight door, the solar collector that is, a solar panel and the DC motor are housed in the top cabinet and under the panel is the exhaust fan and a 12 V direct current (DC). A rack for hanging clothes is attached to the top of the cabinet. The solar panel unit consists of a connected assemblage of a 6 × 10 photovoltaic solar cell. The characteristics of the solar panel have been discussed by some authors (Ayara *et al.*, 2017; Nwoye *et al.*, 2017; Usikalu *et al.*, 2018). The photovoltaic panels absorb sunlight used to generate electricity that serves as the energy source. This solar panel from a mono crystalline type with a 200 W generates the power of the exhaust fan and motor. The dryer is in the open position to orient the solar panel at an angle to face the sun's rays. The photovoltaic cell captures solar radiation and therefore converts it into electricity to power the fan. The fan connected to the dryer sets the air flow from the base upwards and from the cabinet. The relatively dry and flowing state of the air inside the cabinet facilitate the drying process of the items hanged inside the dryer. As air flows in the drying cabinet, it removes and transmits moisture from the clothes to the convection air. The system is therefore an active solar system and requires a mechanical gadget such as an extractor to control the dryer's air section. Figure 3 showed the final assemblage of the dryer components that was measured according to the specifications. This dryer was tested for performance after the design. The efficiency of the cloth dryer was calculated using equation 1and the moisture content of the cloth was determined with equation 2.

Figure 3: Fabricated Solar Cloth Dryer.

$$\text{Efficiency (\%)} = {w_O}/{w_i} \times 100 \qquad 1$$

$$M_D = \frac{W - D}{W} \times 100 \qquad 2$$

where w_o is the mass of the cloth after drying, w_i is the mass of the cloth before drying, M_D is the percentage of moisture content, W is the wet weight and D is the dry weight.

3. RESULTS AND DISCUSSIONS

Some of the quantitative results obtained from the solar cloth dryer and the open sun drying were presented in Tables 1 and 2. figure 4 is the plots from all the results from different fabrics considered for the study. The efficiency of the solar powered cloth dryer was found to be 66.43% and the result is in agreement with the work of (Ekechukwu and Norton, 1999). Figure 4 shows how the moisture content from fabrics of different masses varies with drying time in both solar cloth dryer (SCD) and open sun drying (OSD) at different masses. From Figure 4, it can be seen that SCD is more suitable than OSD in drying the fabric with mass 74 g because SCD reduces the moisture content with minimum drying time. Consequentially, OSD out-performs SCD with a reduced drying time of moisture content of 79 g. In addition, both solar cloth dryer and open solar dryer show a similar trend in moisture content reduction with reduced drying time in fabric 86 g. However, in all, OSD reduces the moisture content of 86 g fabric faster than SCD. Moreover, the quick drop of moisture content in fabric 100 g under SCD within the drying time 15–25 minutes over OSD is noticed. Nevertheless, the moisture content with drying time under OSD is lower than that of SCD. The reduced moisture content with drying time (in the fabric 100 g) is also noted in OSD over SCD. The moisture content of fabric 35 g is seen to reduce with drying time under open sun dryer than solar cloth dryer. Scientifically, a higher diffusion rate is observed in the moisture content of fabric 64 g under OSD when compared with SCD.

Figure 5 depicts the box plots comparing the two distributions. The mean moisture content increases in the order: open sun dryer greater than solar cloth dryer. Therefore, the median of open sun dryer has the potential in reducing the moisture contents quicker than solar cloth dryer because its median is in the upper quartile and the solar cloth dryer taking longer time to reduce the moisture content of the cloth because its median is in the lower quartile. Statistically, both SCD and OSD show different mean moisture content. In addition, OSD shows higher chances of drying the moisture content of the fabrics faster than SCD.

Table 1: Mean Moisture Content and Time Taken by Solar Cloth Dryer

Weight of Dry Fabric = 79g			
S/N	**Wet Weight (grams)**	**Time in Dryer (in mins.)**	**Moisture Content (%)**
1	193.00	0	59.067
2	188.00	5	57.979
3	182.00	10	56.593
4	176.00	15	55.114
5	167.00	20	52.695
6	161.00	25	50.932
7	134.00	30	41.045
8	145.00	35	45.517
9	134.00	40	41.045
10	120.00	45	34.167

Table 1: Contd.,			
11	115.00	50	31.304
12	109.00	55	27.523
13	102.00	60	22.549
Weight of Dry Fabric = 86g			
S/N	**Wet Weight (grams)**	**Time in Dryer (in mins.)**	**Moisture Content (%)**
1	180.00	0	52.222
2	177.00	5	51.412
3	174.00	10	50.575
4	171.00	15	49.708
5	167.00	20	48.503
6	161.00	25	46.584
7	156.00	30	44.872
8	145.00	35	40.690
9	134.00	40	35.821
10	126.00	45	31.746
11	121.00	50	28.926
12	115.00	55	25.217
13	110.00	60	21.818

Table 2: Mean Mositure Content and Time Taken by Open Sun Dryer

Weight of Dry Fabric = 79g			
S/N	**Wet Weight (grams)**	**Sun Drying Time (in mins.)**	**Moisture Content (%)**
1	181.00	0	56.354
2	176.00	5	55.114
3	167.00	10	52.695
4	160.00	15	50.625
5	156.00	20	49.359
6	148.00	25	46.622
7	141.00	30	43.972
8	135.00	35	41.481
9	131.00	40	39.695
10	128.00	45	38.281
11	115.00	50	31.304
12	96.00	55	17.708
13	90.00	60	12.222
Weight of Dry Fabric = 86g			
S/N	**Wet Weight (grams)**	**Sun Drying Time (in mins.)**	**Moisture Content (%)**
1	183.00	0	53.005
2	176.00	5	51.136
3	170.00	10	49.412
4	166.00	15	48.193
5	162.00	20	46.914
6	156.00	25	44.872
7	151.00	30	43.046
8	145.00	35	40.690
9	137.00	40	37.226
10	122.00	45	29.508
11	117.00	50	26.496
12	110.00	55	21.818
13	105.00	60	18.095

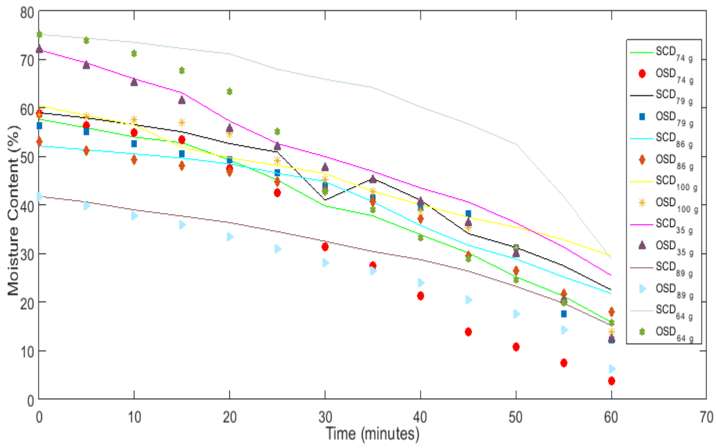

Figure 4: Moisture Content Of SCD (Solid Lines) And OSD (*, ●, ■, ▲, ▶, ⧗ *and* ♦) Against Time

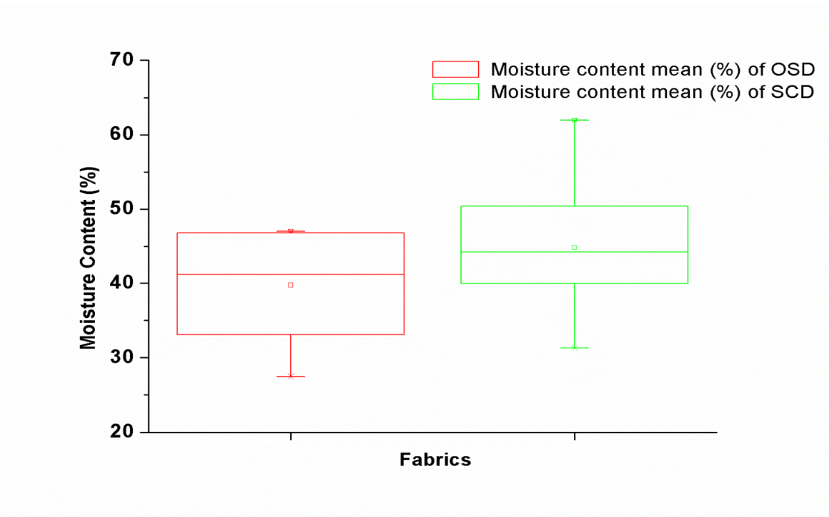

Figure 5: Boxplots Comparing the Two Moisture Content Distributions

5. CONCLUSIONS

Conclusively, this study has designed, constructed and tested the performance of solar cloth dryer against the open solar dryer. And, a salient point has been proven experimentally that open sun dryer is a suitable technique of removing the moisture content as quick as possible in all pieces of fabrics while solar cloth dryer is suitable for specific pieces of fabrics that can get faded with OSD.

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